

HF/UHF DEVIATION METER

E Chicken, MBE, BSc, MSc, CEng, FIEE, G3BIK describes a FM deviation meter which is capable of covering from 3 to 450MHz at deviations of up to 30kHz and offers an additional audio monitor facility.

Any radio engineer or experimenter involved with the construction or maintenance of FM transmitting equipment, will appreciate the need for an instrument by which to measure the deviation of the frequency-modulated signal.

The purchase cost of suitable commercial equipment can be prohibitively high, and the frequency limitations of lower-cost CB or Radio Amateur deviation meters unacceptable, hence the development of this simple to construct, relatively low-cost unit, based on readily available components and housed in a small RF shielded plastic enclosure. It can be used with FM signals over a wide frequency range from HF to VHF, embracing the 27MHz Citizens' band, 28, 50, 70 and 144MHz amateur bands, and the Low, Medium and High bands of Private Mobile Radio. The prototype performed well from 3MHz to 450MHz.

Power supply requirement is 15-20V DC at 50mA from an external source, which is regulated downwards to 12V within the unit, but there is no reason why two PP3 alkaline or ni-cad batteries in series should not be incorporated as an alternative to the external supply. Fig 1 shows in block format the various stages of the instrument, their interconnections and signal routings, whilst Fig 2 gives the full circuit diagram; the component values for which are given in the component list.

Fundamentally, the circuit is a type of superheterodyne receiver, the FM demodulator output from which is displayed on a moving coil meter using a scale calibrated in kHz of deviation. The instrument can also be used to monitor the demodulated audio signal on a small internal loudspeaker, and provision has been made for external access to the pulsed RF harmonics of the VFO, as an elementary source of test signals (extending up to VHF) which could be useful for calibration or general receiver testing.

FREQUENCY CHANGER

The FM signal to be examined (f1), is mixed with a locally generated signal (f2), in a balanced-bridge diode mixer incorporating two Hot-Carrier Schottky diodes D5 and D6, slightly reverse biased via resistors R35-R38.

Schottky diodes were chosen for this application because of their high-speed switching capability and low internal capacitance, which combine to maximise the upper frequency response of the mixer. Capacitor C28 provides DC isolation for the input signal f1, which feeds into the balanced-bridge diode mixer via C31 and C32. Resistor R34 presents an input impedance of approximately 50ohms to the RF signal source.

By simultaneous application of a local oscillator signal f2 to the bridge, the FM input signal is down-converted to a relatively low Intermediate Frequency which faithfully reproduces the original frequency modulation but now on

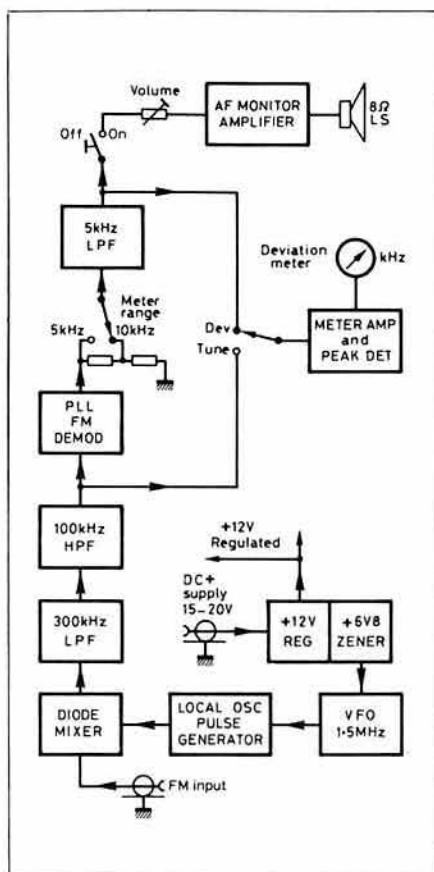


Fig 1. Block Diagram of the Deviation Meter.

a carrier frequency of about 150kHz.

Basically, the difference between this receiver and the usual superhet receiver, lies in the method adopted for the generation of the local oscillator signal. In a conventional receiver, the local oscillator provides an unmodulated continuous wave signal at a frequency close to that of the incoming RF signal, and is arranged to follow exactly any change in signal frequency such that the difference in frequency between the local oscillator and the signal frequency remains constant at the chosen Intermediate Frequency.

In this deviation meter circuit, the local oscillator signal is not an unmodulated continuous wave but is instead a pulsed-train signal with a repetition rate of approximately 1.5MHz, the appropriate harmonic of which is mixed with the FM signal frequency to yield the required IF. The variable frequency pulse train is derived from a standard Colpitts Variable Frequency Oscillator (VFO) designed around transistor TR1, centred on 1.5MHz. Varicap diode D1 in association with a linear potentiometer RV1 allows the frequency of the VFO to be externally adjusted by about 100kHz on either side of 1.5MHz.

Frequency calibration of the VFO is not required, it being sufficient for the purpose that the actual frequency can be externally adjusted by a few kHz about its nominal centre frequency. Because the choice of centre frequency is somewhat arbitrary, it conveniently allows the use of a 100μH fixed-value moulded RF inductor, which together with sound mechanical construction and the stabilised 6V8 DC supply provided by Zener diode D2, ensures adequate frequency stability.

The sinusoidal output signal from the VFO is buffered by emitter follower TR2, amplified and amplitude-limited by transistors TR3, 4, 5 and diode D3, then differentiated at TR6 and TR7 to produce a train of sharp pulses with a repetition rate equal to the VFO frequency. These pulses are applied to a high-frequency switching diode D4, at a voltage amplitude sufficient to overcome the forward bias present on diode D4 via resistors R28, R29, R30, causing the diode to switch off and on in sympathy with the pulse repetition frequency.

The rapid switching action of this diode produces current pulses through the primary winding of pulse-transformer T1, which are rich in harmonics of the VFO frequency, extending well up into the VHF part of the spectrum. In that the usable upper frequency limit of the unit is to a large extent determined by these local-oscillator harmonics, it is possible to extend the range of harmonics produced in this stage by replacing the switching diode D4 with a microwave Step Recovery Diode, but such devices are usually very expensive compared with the 1N4148 silicon diode used in the original design.

Pulse transformer T1 comprises two windings each of four turns of insulated thin wire, using a different colour for each winding, wound in bifilar fashion through a small ferrite ring of about 10mm diameter, or less. The term bifilar means that the two wires are wound through the ring side by side as though they were but one wire.

As the polarity of the pulses from the pulse-transformer to the following diode-bridge mixer is important for correct operation of the mixer, care must be taken to ensure that the connections from transformer to mixer are as indicated by the two black dots on the diagram. The use of different colours for primary and secondary assists with that task.

Positive-going pulses are applied to the balanced-bridge diode mixer via capacitor C27, and negative-going pulses via C26, at an amplitude which is sufficient to overcome the reverse-bias present on the mixer-diodes D5 and D6 respectively. Bridge paths are thereby opened to allow passage of the FM input signal through resistors R39 and R40 in the form of pulses, which are a composite mix of the two signals being applied to the bridge ie the FM input signal f1, and the local oscillator signal f2. The signal voltage developed across high-

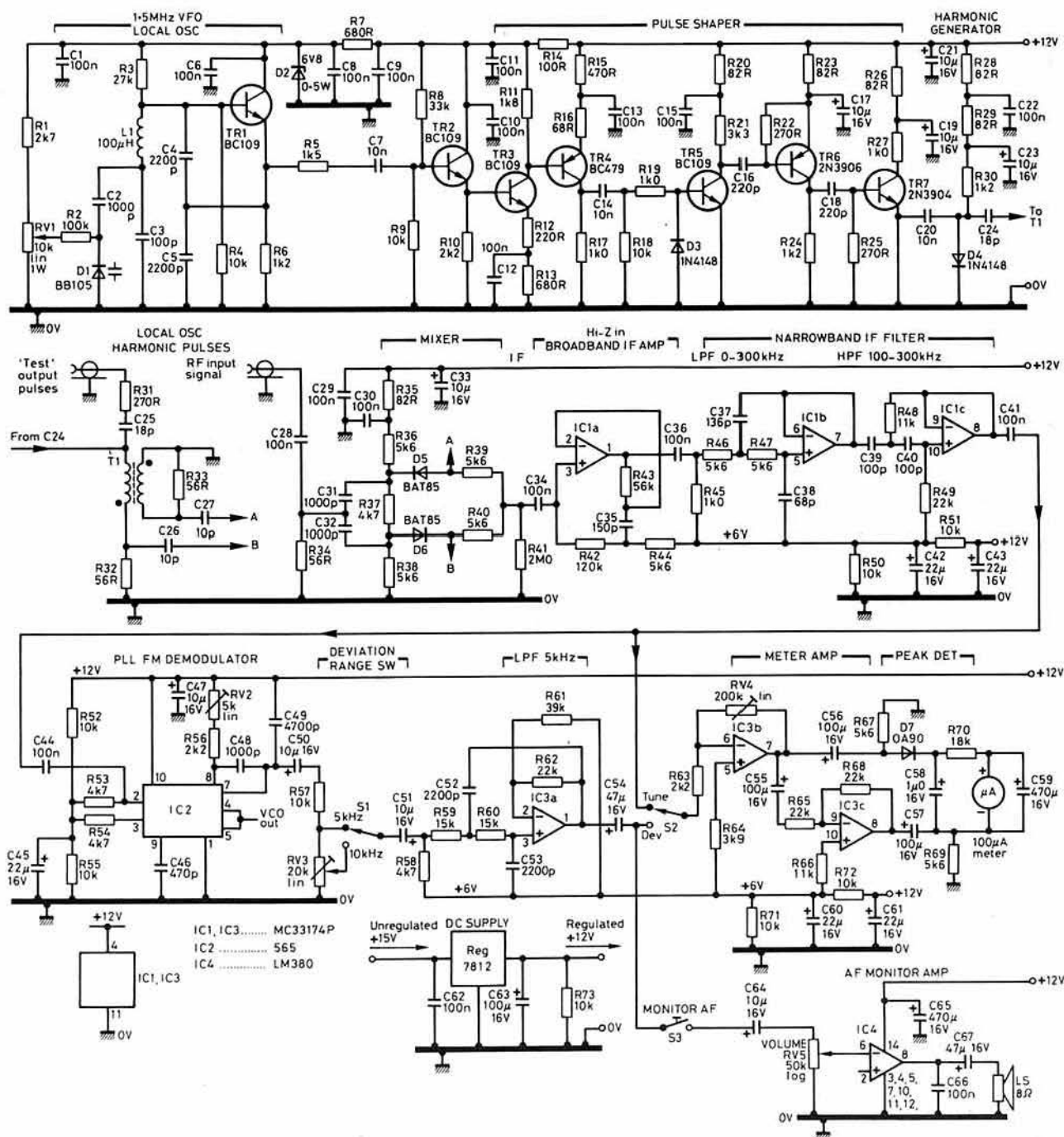


Fig 2. Circuit Diagram of the Project.

value resistor R41, is the algebraic sum of the two omni-directional pulsating signals from mixer diodes D5 and D6 alternatively.

Ideally, the output signal from the mixer should contain no more than the four frequencies f_1 , f_2 , f_1+f_2 , and f_1-f_2 , but in this design it contains a very broad spectrum of frequencies due to the harmonically rich local oscillator signal being applied to the bridge-mixer. This however does not present an operational problem, as it is taken care of in subsequent stages which seek to select only the f_1-f_2

component. From R41, the mixer output signal is passed via capacitor C34 to the input of broadband amplifier IC1a, an operational amplifier configured to present a high input impedance to the input signal from the mixer, with a stage gain of $\times 11$ (21dB). Whilst this is an untuned broadband amplifier (hence should strictly speaking not be referred to as an IF amplifier) it is by the very nature of an op amp not capable of amplifying the very high frequencies present at its input, so automatically provides significant attenuation of that range.

The amplified signal from IC1a is then passed through a tuned amplifier centred on 150kHz, to select the intermediate frequency for subsequent processing. This tuned amplifier which shall now be referred to as the IF amplifier consists of two successive unity gain amplifiers IC1b and IC1c. The first stage, IC1b, is arranged as a low-pass filter with a 3dB cut-off frequency of 300kHz, so passing on to the input of the succeeding stage only frequencies below 300kHz. IC1c is configured as a high-pass filter with a 3dB lower cut-off frequency

of 100kHz, hence is capable of passing only frequencies present at its input which are higher than 100kHz. The combined result of these two unity gain filters is to present at the output of IC1c only those frequencies which fall between 100-300kHz.

Actually, due to component tolerances, interstage loading effects and asymmetrical frequency response of the filters, the *in-vivo* pass-band of the prototype IF amplifier peaked at 130kHz, not 150kHz as was the design intent, but this does not detract from the intended performance of the circuit.

The IF signal is now routed via switch S1 to be processed so that the desired function is achieved. The prime function is to provide an indication of the FM Deviation in kHz, the secondary function being to monitor the demodulated AF on the internal loudspeaker.

Before either of these two facilities can be realised, it is necessary for the instrument to be 'tuned' by varying the frequency of the VFO until the local oscillator signal is such that it combines with the incoming FM carrier frequency to produce the required IF.

TUNING

With switch S2 in the 'Tune' position, any IF signal appearing at the output of the IF amplifier will be passed via C41 to the input of the meter amplifier stage IC3b, the gain of which is presettable by adjustment of RV4 in its negative feedback loop, within the range x1-x20 (0-26dB). The output signal voltage from IC3b is capacitively coupled to diode D7, which in association with capacitor C58 acts as a peak-signal detector. The rectified DC voltage appearing across C58 is directly related to the peak amplitude of the IF signal.

To optimise the sensitivity of the peak detector, the amplified IF signal from IC3b is simultaneously fed to a unity gain inverting amplifier IC3c, the output from which is used to enhance the magnitude of the peak voltage developed across C58, thereby allowing the use of a 100 micro-amp meter as the indicator.

Tuning is simplicity itself. The RF signal to be examined is applied to the input socket either directly by coaxial cable, or by plugging into the socket an elementary pick-up antenna of say 10-20cm length. In either case, the instrument will behave correctly with an input signal as low as 5µV p.d, but it is better to apply a signal level higher than that, say 50µV.

With zero modulation on the RF carrier, the tuning knob of RV1 is slowly rotated whilst observing the meter, and tuned for maximum deflection of the needle. A number of maxima of different magnitudes will be seen, some of which may be similar. The choice is not critical, one which appears to dominate is selected, and the meter deflection carefully tuned for optimum. Switch S2 is now changed over to the 'Deviation' position, and the instrument is ready to be calibrated for FM deviation.

FM DEMODULATION

The bandwidth of the IF amplifier is more than adequate to handle the range of frequency deviation likely to be met in normal use. Although the prototype described here is calibrated up to 10kHz deviation, it has been satisfactorily tested for linearity of up to 30kHz. FM demodulation of the nominal 150kHz IF signal must of course precede any attempt

to measure deviation or to monitor the AF signal.

IC2 is a phase-locked loop (PLL) integrated circuit type 565, which is arranged to act as the FM demodulator. It was chosen for the excellent linearity of relationship between frequency deviation of the input signal and the resultant DC voltage level appearing at the pin 7 output terminal.

Resistors R56 plus RV2, in combination with capacitor C46, determine the free-running frequency of the PLL voltage controlled oscillator, given by:-

$$F(vco) = 0.3/CR = 100-300kHz$$

Presettable resistor RV2 allows adjustment of the VCO centre frequency to match the nominally 150kHz centre frequency of the FM signal present at the pin 2 input terminal; capacitor C48 offers protection against unwanted RF oscillation within the loop.

Frequency-locking range for this circuit is given by:-

$$F(lock) = 0.66 \times F(vco) = 100kHz$$

Capacitor C49 connected between the output terminal and positive supply rail, in association with an integral 3600ohm resistor within the PLL, forms a low-pass filter which determines the frequency capture range of the loop, the expression for which is:-

$$Fc = 0.4 \times \sqrt{(F(lock)/CR)} = 31kHz$$

The strap between pins 4 and 5 connects the output of the VCO to the phase comparator input, at the same time providing a convenient access point for measurement of the VCO frequency.

Before any attempt is made to calibrate or otherwise use the deviation meter, the free-running frequency of the PLL VCO must first be adjusted to 150kHz by means of preset resistor RV2, with either an oscilloscope or a frequency meter temporarily connected to pins 4 and 5.

When the frequency of the input signal falls within the capture range of the PLL, the loop locks into the input frequency. During lock, the average DC voltage level at pin 7 which is the output of the phase comparator, is directly proportional to the frequency of the input signal. Any subsequent variation in frequency of the input signal causes a change in the DC voltage level at pin 7, which is internally fed back to the voltage-controlled oscillator in an effort to maintain frequency equality between the VCO and the input signal.

The resultant variation in DC voltage level at pin 7 in both magnitude and direction, is in direct linear relationship to the variation in frequency of the input signal ie the frequency deviation of a frequency-modulated signal, hence the phase-locked loop acts as a very linear FM Demodulator. Assuming now that the input signal to the instrument is frequency modulated by an audio frequency source, the demodulated signal appearing at pin 7 of the PLL is a true reproduction of the original AF modulating signal.

This is passed via C50 to a potential divider comprising resistors R57 and RV3 which serve as a voltage attenuator to provide two different levels of output signal. These two levels will be subsequently related to full-scale deflections of the indicating meter to read 5kHz or 10kHz deviation, as selected by the Deviation Range switch S1.

From S1 the AF signal is passed via C51 to

the input of IC3a, which is configured as a low-pass filter with an upper cut-off frequency of 5kHz, so filtering out any undesirable higher frequencies from the demodulated signal.

An interesting feature of this particular LFP circuit, is the use of equi-value frequency-determining capacitors and resistors. The stage gain, given in this case by (R63 + R64)/R63 is little more than unity at about x1.6 (4.1dB). C54 offers DC isolation whilst passing the AF signal to one of two routes.

AF MONITOR

The AF signal can be fed to the input of the integrated-circuit AF monitor amplifier IC4 whilst the Tone/Dev switch S2 is in the Deviation position, by pressing the push-button switch S3 and adjusting volume level from the internal loudspeaker by means of the panel-mounted volume control RV5.

This allows the content as opposed to the quality of the demodulated signal to be monitored, and the use of a push-switch seeks to deter the operator from trying to use the monitor during the measurement of deviation.

DEVIATION

With switch S2 in the Deviation position, the AF signal from the FM demodulator is fed into the meter amplifier IC3b and IC3c and subsequent peak-detector, the operation of which was described earlier.

There is however a significant difference in the nature of the two signals presented to this stage as selected by the Tune and Deviation positions of switch S2. In the Tune position, the meter will indicate the presence of a signal whether or not it is frequency-modulated, but when the switch is changed over to the Deviation position, the meter will indicate only when there is modulation present on the original carrier signal.

This is because in the absence of frequency modulation, there is but a steady DC voltage at the pin 7 output of the phase-locked loop, hence there is no AC signal to be passed through the IC3a low-pass filter to switch S2 and onward to the meter amplifier.

As the carrier frequency deviates from its centre frequency due to frequency-modulation, so the amplitude on the DC output signal from the PLL increases and decreases in sympathy, to become in effect a low-frequency AC signal. This is a true replica of the original modulating signal, the amplitude of which is directly and linearly related to the peak deviation of the FM carrier signal. The demodulated signal is then passed via S2 and the meter amplifier to the peak detector to produce an indication on the meter which, being linearly related to the peak amplitude of the derived signal, can be calibrated to read frequency deviation.

At zero frequency-modulation the meter will read zero, but will rise from zero as deviation is applied. If the meter deflection is then arranged to indicate full-scale for a known level of frequency-deviation, all readings at full-scale and below can be readily translated into deviation. For example, the 100 microamp meter chosen for use in the prototype came with a linear scale of 0-10, so by pre-adjustment the full-scale reading of 10 was made to coincide with a deviation of 10kHz, hence scale reading 7 = 7kHz, 5 = 5kHz etc down to zero.

RESISTORS

0-25W Metal Film

R32,33,34	56R
R16	68R
R20,23,26,28,29,35	82R
R14	100R
R12	220R
R22,25,31	270R
R15	470R
R13	680R
R17,19,27,45	1k
R6,24,30	1k2
R5	1k5
R11	1k8
R10,56,63	2k2
R1	2k7
R21	3k3
R64	3k9
R37,53,54,58	4k7
R36,38,39,40,44,	
46,47,67,69	5k6
R4,9,18,57	10k
R48,66	11k
R59,60	15k
R70	18k
R49,62,65,68	22k
R3	27k
R8	33k
R61	39k
R43	56k
R2	100k
R42	120k
R41 (2 x 1M0)	2M0

0-5W Metal Film

R7	680R
R50,51,52,55,71,72,73	10k

POTENTIOMETERS

RV1	10k Lin, 1W
RV2	5k Lin, min.preset
RV3	20k Lin, min.preset
RV4	200k Lin, min.preset
RV5	50k Log, Carbon, min.vol.control

RV1 and RV5 are panel mounting, all Cermet types except RV5.

CALIBRATION

As for the calibration of most measuring instruments, the crunch comes with the requirement for a signal source of known accuracy. The ideal source for this particular application would be an RF signal generator with a frequency range 2 to 450MHz, a frequency-modulation facility with calibrated deviation from zero to 30kHz at an audio-frequency of 1kHz, and with calibrated output attenuation of the output signal down to 5µV pd into 50ohms. Assuming the availability of such a signal source, the signal generator is connected to the FM input socket of the deviation meter to provide a signal of 50µV pd at 50MHz, initially with zero deviation.

With the deviation meter switched on, and with the Tune/Dev switch S2 set to the Tune position, the VFO external tuning knob is slowly rotated until a maximum deflection is obtained on the meter. If the meter deflection is greater than full-scale, the output attenuator of the signal generator must be adjusted to bring the tuning-maximum back onto scale.

A number of maxima of differing amplitudes will be observed as the tuning knob is rotated, the choice of which is not critical. It is sufficient to opt for one which appears to be dominant, and carefully tune for maximum. On switching now from Tune to Dev the meter reading will fall to zero, because the input signal is not as yet being frequency-modulated.

With the deviation range switch of the deviation meter at its 5kHz position, frequency-modulation at the audio frequency of 1kHz and

CAPACITORS

Ceramic, radial resin-dipped, 63V DC

C16,18	220pF
C2,31,32,48	1000pF
C49	4700pF
C7,14,20	10n
C1,6,8,9,10,11,12,13,	
15,22,28,29,30,34,36,	
41,44,62,66	100n

Polystyrene, 160V DC

C4,5,52,53	2200pF
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Silver-mica, 350V DC

C26,27	10pF
C24,25	18pF
C38	68pF
C3,39,40	100pF
C37 (2 x 68pF)	136pF
C35	150pF
C46	470pF

Electrolytic, 16V DC

C58	1.0µF
C17,19,21,23,33,47,50,51,64	10µF
C42,43,45,60,61	22µF
C54,67	47µF
C55,56,57,63	100µF
C59,65	470µF

SEMICONDUCTORS

IC1,IC3	MC33174P
IC2	565
IC4	LM380
TR1,2,3,5	BC109 or 2N3904
TR4	BC479 or 2N3906
TR6	2N3906
TR7	2N3904
D1	BB105
D2	BZY88, 6V8, 500mW
D3,4	1N4148
D5,6	BAT85
D7	OA90
12V REG	7812

MISCELLANEOUS

L1 RF Inductor	100µH moulded Ferrite ring 10mm dia.max., 4 turns per winding, bifilar wound
T1 Pulse-transformer	SPDT Ultra-min. toggle switch
S1,2	SP Normally open, min. push-button
S3	80hm miniature
Loudspeaker	100 microamp fsd, linear 0-10, 50mm
Meter	RF shielded ABS, 190 x 110 x 60mm
Enclosure	3.5mm chassis-mounting
Socket, DC input	50ohm BNC panel-mounting
Socket, RF signal input	50ohm BNC panel-mounting
Socket, test-pulses out	50ohm BNC panel-mounting

with a deviation of 5kHz, is now applied to the carrier signal. The resultant meter deflection is then adjusted by preset resistor RV4 in the meter amplifier feed-back loop, until the meter indicates exactly full-scale.

The deviation meter is switched to its 10kHz range, and the meter deflection will fall from full-scale to a lesser reading. Preset resistor RV3 at the output of the phase-locked loop IC2 is then adjusted until the meter reading is exactly at mid-scale. Assuming that the meter is scaled 0-10, it will be reading 5 to signify a measured deviation of 5kHz at mid-scale on the 0-10kHz range.

Deviation of the FM signal at the signal generator is now increased to precisely 10kHz, at which setting the deviation meter should indicate full-scale. If not, a slight readjustment of RV3 is called for. Deviation is now decreased in steps of 1kHz from 10kHz to zero, to confirm

true linearity of the indicating meter circuit.

While the signal generator is still connected but with zero frequency deviation, it would be prudent to determine the upper-frequency limit of the deviation meter by switching to the Tune position and progressively increasing the carrier frequency in sensible increments and returning at each step, until it is no longer possible to obtain a suitable maximum on the meter. If required, the frequency tuning-range of the VFO may be conveniently measured at the test pulses output socket.

The instrument is now ready for use.

POWER SUPPLY

A single-supply voltage philosophy is adopted for the deviation meter via an integral 12V regulator, so ensuring stability of deviation calibration whilst affording a degree of flexibility in the choice of externally supplied DC voltage level.

All of the discrete transistors are fed from the full +12V regulated rail, except the VFO, the supply for which is further stabilised by a 6V8 zener diode. Split-voltage supplies for IC1, IC2 and IC3 are provided by resistive potential-dividers, with appropriate capacitive decoupling.

Adequate decoupling of the DC supply connections is of the utmost importance in this circuit because of the pulsed nature of the local oscillator and mixer signals, hence the provision of low value decoupling capacitors to filter out the higher frequencies from the supply rails, and microfarad values to deal with the lower frequencies.

CONSTRUCTION

The prototype circuit was constructed on SRBP copper stripboard of 0.1 inch hole-spacing and dual parallel lanes were allocated on the stripboard for each of the several DC supply and return rails.

Component layout is not critical, provided that as with any HF circuit, due attention is given to the shortness of component leads and interconnecting wires, and to mechanical rigidity. Sub-miniature 50ohm coaxial cable is employed for the interconnection between signal input socket and mixer, and miniature screened cable is used between all other panel-mounted components and the circuit board.

The RF screened enclosure is electrically bonded to the negative supply terminal, shown on the circuit diagram as the 0v rail, and the decoupling capacitors associated with the integrated circuits should be connected directly between the supply pins of the appropriate IC.

The panel-mounted miniature volume control was found to be not really necessary in practice, so this could be replaced by a pre-settable potentiometer mounted internally on the circuit board.

As the upper operational frequency limit of the instrument is largely determined by the performance of the local oscillator harmonic-generator diode D4, pulse-transformer T1 and the D5/D6 diode-mixer circuit, particular care should be taken to ensure shortness of component leads and symmetry of component layout for this section of the circuit.

It is worth noting that a suitable Step Recovery Diode and pre-wound ferrite pulse-transformer were seen to be available from J Birkett Ltd at about £1 each. □